PERU HEALTHY KITCHEN/HEALTHY STOVE PILOT PROJECT

ANNEX VI – Pulmonary Health Assessment

ANNEX VI. Pulmonary Health Assessment

Abating Indoor Air Pollution Improved Lung Function Tests:

Improvement in Pulmonary Obstruction Measured in a Rural Andean Population after a "Rocket Stove" Program Reduced Exposure to Biomass Cooking Smoke

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Abstract

__Objective__: Using an analogy to studies of smoking cessation, we should find that lowering indoor air pollution (IAP) with improved cookstoves should improve lung airflow.

__Materials and methods:__ Airflow rates in adult household members and kitchen particulate levels were measured before and months after installation of chimney stoves in households that had been cooking on open fires.

__Results:__ Division into 2 groups by particulate reduction showed a trend of improvement in exhalation force with better reduction among subjects with tests that fully met clinical validity criteria. Removing a subject whose cooking status changed, as well as an outlier, made the difference significant ($p < 0.01$). The difference was also significant ($p < 0.05$) after adding in subjects whose tests did not quite meet validity criteria. Stratifications by gender and baseline airflow showed significance for women and those without baseline decrease. Mean differences were similar across gender. Carbon monoxide (CO) reduction and particulate reduction correlated. In multivariate analysis, just baseline exhalation force and a statistic that combined percent and absolute particulate reduction remained predictors of improvement.

__Discussion:__ Biomass smoke exposure is known to correlate with death and disability where poorly ventilated burning is done for cooking, but what degree of reduction in exposure is important in prevention of airway problems is poorly defined. These results suggest that obtaining good reduction of particulate exposure will lead to less obstructive lung disease morbidity. This smoke pollution also causes a large number of deaths from pneumonia, especially in children. Thus, this intervention has potential to also reduce the high rate of under-5 mortality in impoverished countries.

Keywords: **Indoor air pollution, lung diseases, biomass fuels, poverty**

Executive Summary

In August 2005 and 15 months later, data were collected by survey and breathing tests in adults from 44 households that initially used indoor open fires to cook. Levels of respirable particulates and carbon monoxide in the cooking areas of the households were also measured before and after installation of "rocket" stoves with chimneys.

Symptomatic lung disease was common in these subjects despite tobacco smoking not being a significant issue. At baseline, virtually all respondents reported a chronic cough. Many had sufficient symptoms to be classified as having chronic bronchitis. Repeated survey the next year showed nearly complete resolution of all symptoms. By analogy to the improvement in breathing environment that occurs with tobacco smoking cessation or reduction of high level exposure to second-hand smoke, lower amounts of kitchen pollution should also reverse rates of decline in breathing obstruction (FEV1% measured by spirometry) as it does with cessation of cigarette smoke exposures. By an extrapolation from the literature on cessation of tobacco smoke exposure, the reduction in the airway damage associated with indoor air pollution (IAP) from cooking fire smoke should have lead to a 2.78% average increase in FEV1% over the follow-up period.

Some problems occurred with our data collection, largely due to loss to follow-up and spirometric tests that did not meet clinical reproducibility criteria. In the 15 subjects with fully valid tests in both years, there was an overall decrease in FEV1% of –1.38% (95% confidence interval was clearly different from the 2.78% improvement expected). This might have meant that the project failed to achieve meaningful reductions in lower respiratory tract consequences of biomass smoke exposure. However, there were large differences in the degree of reduction of biomass smoke pollution as indicated in the monitoring data for respirable particulates and carbon monoxide. An examination of this data set showed that combined cut-points of both ">100 mcg per meter squared" and ">64%" reduction in particulates discriminated between groups with better and worse spirometry results but this did not reach significance at the traditional $p < 0.05$. However, one of these subjects wasn't cooking initially but was at follow-up. Another subject was an outlier with an FEV1% increase of 8.82%; this is consistent with this subject having asthma. The analysis was repeated with just the other 13 individuals. The difference between groups was then significant at $p < 0.01$.

Examining all of our data, including those with too much variation to meet clinical validity criteria, increases variance and reduces the likelihood of a statistically significant difference. But this could reassure us that the above results are not just due to post-hoc analysis. Doing this gave us 36 subjects. Despite the increased random error from including those with less repeatable results, this yielded a very similar analysis after dropping 4 outliers whose large FEV1% changes indicated they probably had asthma. The difference between groups with better and worse reductions in particulate pollution was significant at $p < 0.05$. The confidence interval for the average FEV1% change in the group with better reductions in particulates was –0.88 to 2.35% improvement. While this is not quite as good as hoped for by analogy to cessation of high-level tobacco smoke exposure, it is still reassuring that this amount of reduction in cooking smoke exposure can make a difference in the rate of progression of chronic obstructive lung disease.

This analysis focused on particulates but all of these households also had analyses of CO levels in both years. Scattering either the change in CO or its percentage drop from baseline against the change in FEV1% (or adding them to a regression model along with the change in particulates) shows no correlation so it is clear that the lung function results are associated primarily with the ability of the "rocket" stove installations to markedly reduce particulate pollution when installed and used properly.

Using the larger data set, it was also possible to check whether results varied by gender or by presence or absence of baseline obstruction. For the 17 men, there was no significant difference in FEV1% change between groups with more or less particulate reduction in the kitchens of their households. For the 15 women, there was a difference that was significant at $p < 0.05$. Although the mean changes were similar for both genders, the higher variance among the men may reflect wider variation in time spent in the kitchen. Although the majority of men in this sample cooked at least once a week, the women were the primary cooks in all these households so this result is consistent with women having had more chance of benefiting from reduction in kitchen smoke.

Comparing those with evidence of obstruction at baseline showed them to have improved FEV1%; those without didn't seem to benefit ($p < 0.0005$). Linear regression that included this variable did not negate the statistical significance of the reduction in particulate exposure. Having the statistical program (STATA 8.2) pick predictors of improvement (by backwards, stepwise exclusion) showed that just these two variables are significant. These results are especially striking because baseline obstruction does not predict achieving better particulate reduction (8 did and 9 didn't). Those without baseline obstruction also showed nearly equal levels of better reduction (6 did and 9 didn't). So reducing particulates by this amount has real benefit. In this sample, the impact seems to only be measurable for those already damaged by many years of smoke inhalation.

Discussion:

It is widely known that biomass smoke exposure is associated with death and disability in households in the poorer parts of the world where poorly ventilated burning of various fuels is done for cooking. However, it is still unknown what degree of reduction in exposure is important in prevention of airway problems. The largest mortality burden from smoke pollution is due to lower airway infections (mostly in small children who stay near the kitchen fire with their mothers for long periods). Measuring impact on this would likely require a large number of households over several years and proof of the amount of pollution reduction in all of the test households.

While the impact of chronic obstructive lung disease on mortality is less well defined, the most important airway damage in this disease is in small airways. Damage to these same small airways is also the primary reason that indoor air particulate pollution increases deadly infections. Measuring changes in the continuous decline in force of exhalation among those exposed to damaging levels of particulates gives a valid measure of progression of their disease. The added benefit of a known, and relatively large, reversal of effect in the first month after cessation of indoor exposure to another biomass smoke source (tobacco) made this an especially appealing model for study.

In terms of airway symptoms, there was no difference in their alleviation by the success (or lack thereof) in reducing measured IAP. Chronic cough was highly prevalent in the first survey and virtually disappeared in the second. This may be due to problems in administering the survey. It is also possible that it reflects changes in production of larger particles that may induce more cough through effects on the upper airway. Since total airborne particulates were not measured, we don't know whether this stove design in this setting reduces them more than it does the respirable particulates that were measured and which are known to have major impact on the lower airways.

This study did not try to find out which patients had asthma. Because of the higher variability in their FEV1% changes after "smoking" cessation (due to other interval factors and illnesses), the handful of people whose large change in FEV1% from year to year made asthma likely was simply excluded. This weakness of our study could be avoided in larger studies with enough asthmatics for a stratified analysis.

The expanded analysis of 32 individuals gave us a data set with nearly equal numbers of men and women. Both genders were equally affected at baseline, likely because most of these men cooked regularly and because of the attractiveness of the warmth of the hearth during the coolness of morning and evening cooking times in this high altitude area. Women had a more significant FEV1% change in this sample, which may reflect the IAP reduction from a baseline of higher, longer exposures. Longer follow-up or more data from more households could help solidify this finding.

Finding some means of going back and rewarding everyone who completes the follow-up testing could be one way of accomplishing this. Most individuals in the project area depend on subsistence agriculture and it was evident that people lacked motivation to do the follow-up testing. There may also have been issues around the strangeness of the test.

The reason for testing the association between a combined reduction statistic (both percentage and absolute) for particulate pollution and improved lung function involves the stationary location of the pollution measurement equipment. It is unlikely to capture an equal proportion of the breathing zone smoke that each cook is exposed to in each kitchen. The figures for each kitchen needed to be seen as more relative than absolute. However, if a kitchen started with low levels of particulates, it is unlikely that a 65% or greater reduction in the level of fine particles is anything more than random day-to-day variation so an absolute decrease of >100 mcg per meter squared was also required to put a household in the category of better improvement in IAP.

While reductions in CO did not associate with the improvement in lung function, there are other known health benefits of these CO reductions (e.g. in reducing stillbirths and low birth weight in newborns and in exacerbations of ischemic heart disease) so it is also encouraging that almost all of the households with good particulate reductions had substantial reductions in CO.

Expanding this study could solidify our findings and address other health effects of IAP. It would be especially appealing to do a case-control or ecologic study by examining records of pneumonia diagnoses at the two health posts in the area.

Introduction

The food of about 2.4 billion people worldwide is cooked on open fires with biomass fuels (wood, dung, and crop residues), often indoors with little or no ventilation. As reported by Ezzati et al. (2002) this leads to much ill health from indoor air pollution (IAP). Indoor air pollution is thought to contribute greatly to the incidence of pneumonia and lower respiratory infections that are the leading cause of death in small children. Smith et al. (2000) note that this is likely because children often stay near cooking fires with their mothers for long periods. Ezzati and Kammen (2001) have shown that infection rates differ by IAP exposure level but, as stated by Smith (2002), the reduction needed to reduce infection rates is not fully tested.

Smith et al. (2006) have published preliminary results from the RESPIRE Guatemala study showing a trend towards reduced pneumonia in small children. However, most other research, such as that on improved ventilation by Akunne, et al. (2008), that shows a beneficial effect on respiratory infections of measures to reduce IAP has not differentiated between upper and lower respiratory infections. Bruce, N et al (2007) have noted how difficult this distinction is to make when laboratory and X-ray testing are not available.

The same damage to the small airways that leads to the increase in respiratory infections like pneumonia also causes chronic obstructive pulmonary disease (COPD) in adults. According to Rabe and Soriano (2006), COPD is common from biomass fuel use, though the burden is not well quantified. By lowering biomass IAP, development of this breathing obstruction in exposed individuals should decrease. Scanlon et al (2000) found that a year after COPD patients quit smoking tobacco, airflow improved when measured by spirometry as FEV1% (Forced Expiratory Volume exhaled in the first second expressed as a % of total lung volume). By testing airflow before and the year after installing improved cookstoves to reduce IAP, we hoped to find a similar improvement in lung health in project participants in the Andean highlands.

The initial plan was to compare changes in airflow in women versus men because women, as primary cooks, are more highly exposed to biomass smoke IAP. However, men frequently cooked in this region even if not as much as women. Men's exposure is also high from congregating near fires during cooking times in this high-altitude, cool temperature location. Thus, we examined airflow improvement overall as is seen in ex-smokers and those whose heavy exposure to second-hand tobacco smoke has been eliminated, like the non-smoking Scottish bar workers studied by Menzies et al. (2006). Their FEV1 (Forced Expiratory Volume exhaled in the first second) improved greatly a month after a smoking ban was instituted. Age-related decline for these workers had resumed on retesting after the second month. Factoring in the percentage increase in FEV1 in this bar study with the longer term decline from aging noted when comparing smokers with ex-smokers (Scanlon et al, 2000), we thought our subjects in Peru should also have improved lung capacity at follow-up the next year.

Materials and Methods

In August 2005, as part of an improved stove project in several villages in the Peruvian Andes, we surveyed adults from 44 households where cooking was done over indoor open fires. We used a brief pulmonary health questionnaire and spirometry to test FEV1%. The program was multi-faceted, using micro-credit based on animal husbandry, local health promoters, and training of local people to make and install the stoves. These were chimney stoves of a design that is known as “rocket” technology. Bryden et al. (2005) have shown that these stove models improve combustion and heat transfer, thus reducing firewood use and IAP, but stove installation, maintenance, and usage issues can lead to wide variation in IAP reduction. In November 2006, data collection was repeated several months after the installation of the improved cookstoves.

Initial data were obtained from 82 individuals. Of these 82, there were 57 whose airflow tests met clinical criteria for reproducibility. Of the 82, only 55 agreed to follow-up testing. Only 37 of these had valid tests; 22 had lung capacities that varied $\leq$ 5%; only 17 had reproducible tests in both years. Two of these lived in homes that did not have IAP monitoring both years, leaving 15 individuals with IAP results for both years who met clinical validity criteria

Monitoring of IAP in these homes included 24-hour measurement of particulate IAP with a pump and filter, capturing particles smaller than 4 microns (PM_4). IAP monitoring was conducted by an engineer whose team simultaneously measured carbon monoxide levels with a T82 Datalogger. Equipment was placed following standards for location of monitoring devices in the cooking area published by the Indoor Air Pollution Team at the School of Public Health, University of California, Berkeley (2005). IAP data for households was collected for 24 hours on one occasion before the installation of improved cookstoves, and once several months after installation.

Results

Participants were also questioned about their overall health and lung capacity. The short questionnaire about illness episodes, chronic cough, and shortness of breath with various tasks revealed striking levels of symptoms at baseline, especially chronic cough. Many had sufficient symptoms to indicate chronic bronchitis. At follow-up, almost all symptoms had resolved, regardless of whether IAP improved or worsened.

At baseline, many of the health assessment participants had below normal FEV1%, despite almost no tobacco smoking (no women smoked; a few men smoked occasionally, but none smoked as often as once in a week). We expected average improvement in our subjects’ FEV1% from the first year to the second year (if they were comparable to former smokers and bar workers no longer exposed to smoke), but airflow dropped -1.38% (95% confidence interval, -3.77 to +1.01). These results are shown in **Table 1 on the next page**

Table 1. Results for the 15 individuals with valid test results from both years

Gender	Baseline FEV1%	% change in FEV1%	PM 4 at baseline	PM 4 at follow-up
F	85.04%	-6.61	94	617
M	81.51%	-6.41	121	30
M	82.30%	-1.89	2290	288
M	82.07%	-2.5	650	370
M	81.27%	-0.95	1430	32
M	80.60%	-2.09	44	161
M	80.19%	-6.65	240	307
M	85.25%	-4.29	94	122
M	61.79%	+8.82	70	83
F	82.37%	-0.19	2546	256
M	65.33%	+3.05	543	ND
M	72.66%	-4.81	2281	ND
F	85.27%	-0.93	565	46
F	81.13%	+1.08	169	45
M	69.91%	+3.73	592	134
Mean	78.45%	-1.38	782	192

These results might indicate no reduction in lung damage in these participants despite > 75% average reduction in PM_4. However, household IAP monitoring data showed large differences in IAP reduction. Thus, comparing the improvements in obstruction between those living in households with greater versus little or no IAP reduction seemed logical. Stratifications by absolute PM_4 reductions or PM_4 at follow-up did not show a distinct correlation between IAP reduction and improved lung function but splitting the subjects into two groups by percentage reduction (65% or greater) showed a more distinct division. A combined cut-point of PM_4 reduction of both “>100 mcg per meter cubed” and “>64%” was even more clear but the difference between groups was not quite significant at $p < 0.05$. This difference is shown in section 1 of **Table 2, on the next page**.

Table 2. Detailed breakouts of test subjects, by group

GROUPS	#subjects	Mean	Std. Err.	Std. Dev.	95% Conf. Interval	
FULLY ACCEPTABLE TESTS IN BOTH YEARS						
Poor IAP	7	-2.81857	2.071386	5.480372	-7.88707	2.24993
Good IAP	8	-0.11375	0.970916	2.746166	-2.40960	2.18210
difference		-2.70482	2.287645		-7.91954	2.50990
						p = 0.2688
FULLY ACCEPTABLE TESTS IN BOTH YEARS MINUS 1 OUTLIER AND 1 SUBJECT NOT COOKING						
Poor IAP	6	-4.75167	0.863259	2.114544	-6.97075	-2.53259
Good IAP	7	1.70e-08	1.111976	2.942012	-2.72091	2.72091
difference		-4.75167	1.407731		-7.85948	-1.64385
						p = 0.0064
ADDING-IN 5 NEARLY ACCEPTABLE TESTS[*] MINUS 3 OUTLIERS AND 1 SUBJECT NOT COOKING						
Poor IAP	9	-3.76222	0.879365	2.638095	-5.79004	-1.73440
Good IAP	9	0.31444	1.024636	3.073907	2.04837	2.67726
difference		-4.07667	1.350245		-6.94442	-1.20891
						p = 0.0083
19 TESTS WITH HIGH INTRAINDIVIDUAL VARIANCE BUT < 20% YEAR-TO-YEAR FVC[**] CHANGE						
Poor IAP	12	-0.41583	0.864684	2.995352	-2.31899	1.48732
Good IAP	7	1.47143	0.998688	2.642281	-0.97227	3.91513
difference		-1.88726	1.321006		-4.71944	0.94491
						p = 0.1749
THESE 19 ADDED TO THE ORIGINAL 13 FULLY VALID TESTS (4 OUTLIERS STILL EXCLUDED)						
Poor IAP	18	-1.86111	0.800832	3.397644	-3.55072	-0.17150
Good IAP	14	0.73571	0.746421	2.792853	-0.87683	2.34826
difference		-2.59683	1.09475		-4.83298	-0.36067
						p = 0.0243
RESULTS FOR JUST THE MEN IN THIS SET OF 32 SUBJECTS (1 OUTLIER STILL EXCLUDED)						
Poor IAP	10	-1.201	1.184457	3.745582	-3.88043	1.47843
Good IAP	7	0.87	1.356727	3.589564	-2.44979	4.18979
difference		-2.071	1.801013		-5.94922	1.80722
						p = 0.2702
RESULTS FOR WOMEN IN THIS SET OF 32 SUBJECTS (NON-COOK AND 3 OUTLIERS EXCLUDED)						
Poor IAP	8	-2.68625	1.036641	2.932064	-5.13752	-0.23498
Good IAP	7	0.60143	0.753375	1.993242	-1.24201	2.44487
difference		-3.28768	1.281483		-6.07145	-0.50391
						p = 0.0243
COMPARING THOSE WITH AND WITHOUT BASELINE OBSTRUCTION (FEV1% <80)						
Poor FEV1	15	-2.816	.6744273	2.612046	-4.26250	-1.36950
Good FEV1	17	1.12	.696054	2.869904	-0.35557	2.59557
difference		-3.936	.9691973		-5.91547	-1.95653
						p = 0.0003

*These extra tests were from individuals who accomplished two valid tests in one of the two years and had FVC that was less than 5% changed from year to year. The best test from the year without 2 valid tests was used for comparison with the other year.

**Many things contribute to unacceptable variations in FVC (the amount of air that can be exhaled from the deepest breath possible). More problems with mucus plugging in one year than the other could be one reason. The percentage exhaled in the first second would be much less affected by this. The 20% cutoff was selected due to the authors perception that most of the subjects with >20% FVC variation had not been able to be coached into doing the tests properly.

The large variance among those with less improvement indicated possible outliers. There was one outlier with a large effect on the data average. He had improved 8.82%, beyond the 99% confidence interval (C.I.) for non-asthmatics in the smoking ban study but within the 95% C.I. for asthmatics. Removing that outlier from the data analysis, since he may have asthma, along with another subject we learned hadn't been cooking the first year but was cooking at follow-up, gave significant results (**Table 2, part 2**).

Further analysis was done using tests that came close to clinical reproducibility criteria. There were 7 subjects with $\leq$5% difference in total volume exhaled between a year with two tests that agreed and the best test in the other year; removing two outliers (whose tests showed changes of 23% and 15% in FEV1%) left 18 total subjects. The difference in FEV1% change remained significant (**Table 2, part 3**). Adding more tests with variation exceeding validity criteria in both years increased the variance further, reducing the likelihood of a statistically significant difference, but should not introduce bias and may add confidence that the small data set results were not due to post-hoc analysis finding chance differences. This gave 36 subjects from 25 households (8 remained excluded for inconsistency in all tests in 1 year or because total exhaled volume varied >20% between years). With outliers excluded as probable asthmatic, the additional tests lack significance by IAP category (**Table 2, part 4**) by themselves. However, combining them and the initial 13 yields a significant result for 32 subjects (**Table 2, part 5**). One household had no detectable particles the second year, which could mean no cooking was taking place, or suggest monitoring equipment failure. Removing these subjects still yields a significant result ($p = .0124$).

Stratified analysis was done by gender since women, as the usual primary cooks, are more exposed. The difference did not reach significance for men but it did for women (**Table 2, parts 6 and 7**). Overall means in the exposure groups were similar so this may just be due to higher variance among the men.

Excluding 4 outliers who might be asthmatic (|%change in FEV1%| > 8), 17 had some baseline airflow obstruction (FEV1% <80). These17 had a significant improvement without stratifying by IAP compared to 15 with no obstruction (**see Table 3 on the next page**), raising the possibility that improvement in people who already have lung damage might not be dependent on achieving this level of reduction in PM_4. However, in multivariate analysis, PM_4 improvement remained an important predictor after controlling for baseline obstruction (**see Table 4, on the next page**). This was somewhat surprising since this group did not achieve better particulate reduction (8 did and 9 didn't) than those without baseline obstruction (6 did and 9 didn't). Perhaps those with more airflow problems were motivated to decrease their personal exposure to the ambient PM_4 that was measured (e.g., by doing less of the cooking tasks in the household). Alternatively, their sensitivity to particulates may be different.

Table 3. Multivariate analysis of baseline obstruction and good versus poor IAP change

TABLE III

CHANGE IN FEV1% FOR THOSE WITH AND WITHOUT BASELINE OBSTRUCTION (FEV1% <80)

FEV1% ≥80	15	-2.816	.6744273	2.612046	-4.26250	-1.36950
FEV1% ≤80	17	1.12	.696054	2.869904	-0.35557	2.59557
difference		-3.936	.9691973		-5.91547	-1.95653

p = 0.0003

Table 4. Multivariate analysis showing PM_4 improvement as an important predictor after controlling for baseline obstruction

TABLE IV

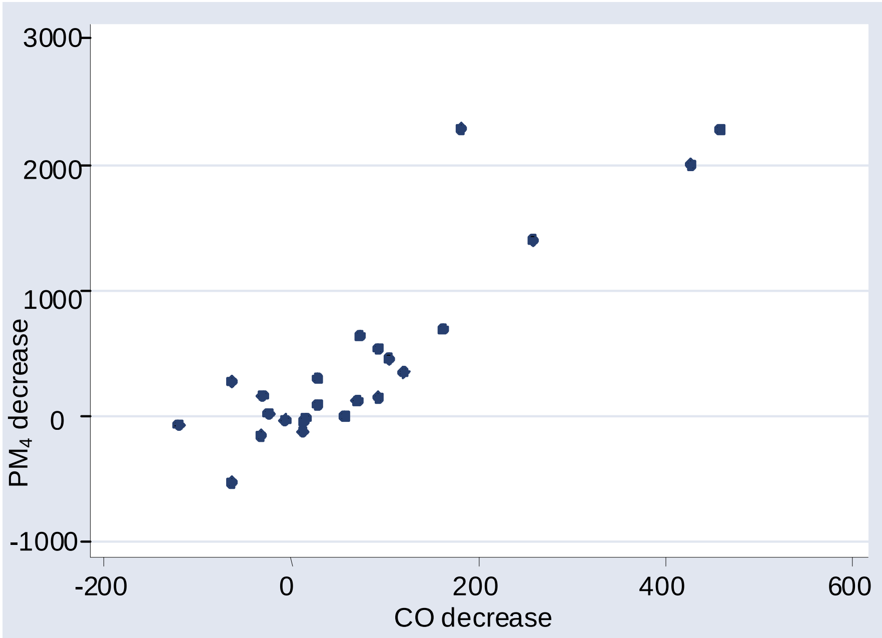
MULTIVARIATE ANALYSIS OF BASELINE OBSTRUCTION AND GOOD VS. POOR IAP CHANGE

FEV1change	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
IAP reduced	2.327417	.9019702	2.58	0.015	0.482681	4.172154
baseFEV1% <80	3.771712	.8966488	4.21	0.000	1.937859	5.605564

Further analysis using multivariate regression modeling showed that adding percent reduction in PM_4 did not add more predictive value, but absolute reduction added a small amount. This raises the possibility that a larger data set might show more value in just one of these reduction statistics or in different cutoffs of the absolute and percent reductions used in this combined statistic.

This analysis focused on particulates, but households also were monitored for carbon monoxide (CO) levels in both years. PM reductions correlated to CO reductions, as shown in **Figure 1**, but adding either change in CO or its percentage drop did not aid prediction.
Letting the statistical program pick airflow improvement predictors (backwards, stepwise exclusion with gender, CO, absolute and percent reductions in PM_4, the combined cutoff, and presence of baseline obstruction) showed that baseline obstruction and IAP reduction (by the combined cutoff) were the only significant variables.

Figure 1. Correlation between CO and PM decreases



Discussion

This project aimed to show that a locally constructed “rocket” stove (with a minimal number of components that would not be difficult to obtain and maintain) would reduce some **harmful** effects of biomass smoke. Although there were problems with our testing that make it hard to be sure that the results are meaningful, there is a suggestion that before and after stove installation measurement of FEV1% could be a valuable assessment tool.

The relative simplicity of measuring a continuous decline in airflow among those exposed to damaging levels of fine particulates from cooking fires made this a logical surrogate measure for morbidity and mortality from IAP. Knowing that a month after cessation of indoor exposure to another biomass smoke source (tobacco) leads to a relatively large improvement in airflow made this an especially appealing model for study. Even if biomass smoke exposure reduction does not prove to correlate with reductions in lower airway infections in larger studies, it is important in itself, since damage from exposure leads to COPD, which can cause substantial morbidity in middle-aged people. Reduction in airway irritation is another benefit (although that probably pales in comparison to the many health needs in impoverished communities). This paper has not focused on those symptoms because of survey problems and their relatively lower health impact.

We were surprised that our survey found no difference in alleviation of symptoms by success (or lack thereof) in reducing measured IAP. Perhaps bias was introduced by the person translating questions into Quechua (a local nurse or the local project engineer). It is also possible that the lack of correlation of symptoms with PM_4 reduction is due to differential reduction of smaller particles (<PM_4) compared to larger ones that are removed from inhaled air in the upper airways. These larger particles may have more impact on cough, amount of sputum production, and number of upper respiratory infections, which may be more relevant to the symptoms on the questionnaire. Subjects reported few lower respiratory infections at baseline so significant improvement could not have occurred or been measured at the follow-up testing.

Because of the complexity of testing for this disease, this study did not try to find out which patients had asthma, which responds to many other interval factors that impact lower airway narrowing (and thus change FEV1%) through inflammation. The Scottish bar smoking ban study had sufficient numbers of asthmatics to overcome their high variability in response before and after the smoking ban. In the Peru study, the handful of people whose large change in FEV1% from year to year made asthma likely were too few for stratification within the data we collected.

The expanded analysis of 32 individuals had nearly equal numbers of men and women. While it was surprising to find that both genders were equally affected at baseline, most of these men did cook regularly and might have congregated near the fire during the cool morning and evening cooking times. The significant effect of greater PM_4 reduction among the women is reassuring that this type of intervention is meaningful for those who usually have the higher exposure. Longer follow-up testing in a larger portion of the women in the initial sample could help solidify this finding.

Finding the resources to go back and reward those who complete the follow-up testing could be one way of accomplishing this goal. People in this area are mostly working in subsistence agriculture and it was evident that many lacked motivation to do the follow-up testing.

The decision to use a statistic combining percent and absolute reductions of IAP came from observing that the stationary location of the measurement equipment would not capture equal proportions of smoke inhaled in each kitchen since particulates do not disperse evenly. As Cynthia, AA et al (2008) have noted, patterns of air currents and the height and habits of the cook would all contribute to differences between measured IAP and what was actually inhaled. Thus, levels need to be seen as relative but, if a kitchen started with low IAP levels, it seemed likely that > 65% reduction was just random day-to-day variation. Therefore absolute reduction was included in the combined cut-off used for comparison. Even if this reasoning proves invalid with further testing, the results would still be explainable since people in households that started with low exposures wouldn't have the improvement expected from "smoking cessation."

It would also be helpful to do more analyses of this population for other effects of both the particulate pollution reduction and the reduction in CO levels. Carbon monoxide has not been associated directly with airway disease so it is not surprising that it did not correlate with improvement in lung function here. However, there are other known health benefits of these CO reductions, so it is encouraging that almost all of the households with good particulate reductions had substantial reductions in CO. Their mean decrease was 183 ppm (range 28 to 458) versus a mean increase of 18 ppm (range 120 to –57) in those with little or no reductions in particulates.

These results will likely not be easily generalized to other settings for several reasons. The location in the Andes at up to 3,200 meters above sea level may have some effects on the formation and behavior of particulates and on lung responses. The ethnic make-up of the population and their lung development and responses in this area of lower atmospheric pressure also might mean that other populations might have different results.

The use of equipment measuring particles <4 microns means that results would probably be somewhat different for studies that measure particles <2.5 or 10 microns or total particulates (but it is probably best to measure the smaller particles if possible since they have greater impact on lower airways). Nonetheless, we succeeded in showing that it is possible to obtain real improvements in lower airway function in a subset of households with significant IAP reductions after an intervention to promote the use of low-cost, efficient stoves with so-called "rocket" stove design characteristics. At follow-up, this group all had PM_4 $\leq$310 micrograms/meter^3 (average of 123.2), which represents $\geq$69% reduction (average 86.5%) in respirable particulates with the new stoves. The 14 people tested in these 10 households with better reduction in IAP had an average increase in FEV1% of 0.74% while the 18 subjects in the 12 households with little or no reduction had an average worsening of 1.86%.

The lack of prominence of IAP reduction efforts in the health and development literature is surprising. As stated by Rehfuess et al. (2006), there is an “urgent need for development agendas to recognize the fundamental role that household energy plays in improving child and maternal health and fostering economic and social development.” This important area for improvement in the health of impoverished people worldwide may be relatively neglected because it is unclear how much health improvement will actually result from various programs to reduce IAP. Thus, more studies of actual health outcomes from reductions in exposure to biomass cooking smoke pollution are needed.

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